Compound Actuator for Linear Piezoelectric Motor having High Thrust Force

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Abstract

In order to excite an effective vibration in the piezoelectric linear actuator, we proposed the compound piezoelectric linear actuator for high thrust force based on “shaking beam”. The compound actuator is consisted of two shaking beams and is rigidly fastened. Acoustical connection between each converter is weakened by using four grooves and a hole of the compound actuator. Finite element method (FEM) was used for defining structural and electrical boundary conditions for piezoelectric actuator. FEM analysis showed that the compound actuator’s trajectory is an elliptical motion.

Introduction

High speed and high accuracy positioning systems are essential elements in advanced manufacturing systems such as the semiconductor industry. Demands of a new type of displacement transducers, which can adjust exact position or drive objects with high accuracy increase significantly.

There are many distinct constructions of the actuators that are used to transform mechanical vibrations of the piezoelectric vibrators into linear or rotational movement of the slider.[1] New idea of elliptical trajectory formation of the actuator for the piezoelectric linear ultrasonic motors is introduced in the paper. Based on the elliptical trajectory formation, the new construction of the actuator called “shaking beam” was developed. Elliptic trajectory of the contact point is achieved by using superposition of two resonance vibration modes of the actuator, i.e. longitudinal and flexural vibrations.

The compound piezoelectric linear actuator with two shaking beams for high thrust force based on shaking beam was introduced to excite an effective vibration in the piezoelectric actuator.

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Concept of shaking beam actuator

Traction force or moments of the ultrasonic motor are proportional to the normal force that presses actuator to the mobile element (slider or rotor) of the motor [1, 2]. But an increase of the traction force by increasing pressing force of the actuator leads to the resonance loss of the system and changes interaction balance of the used oscillations modes. We introduced a new principle of the closed trajectory formation for the contact point of the actuator using only one exciting mode or resonant oscillations. The principle is based on exciting the free ends of the beam by two harmonic oscillations that have identical frequency and phases are shifted by $\pi/2$ [3]. Movement of the beam looks like beam shaking and it is evidently visible a closed trajectory movement of the driver end d of the beam from Fig.1.

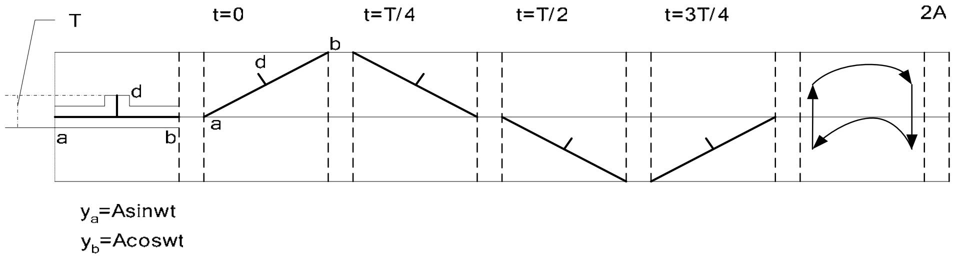
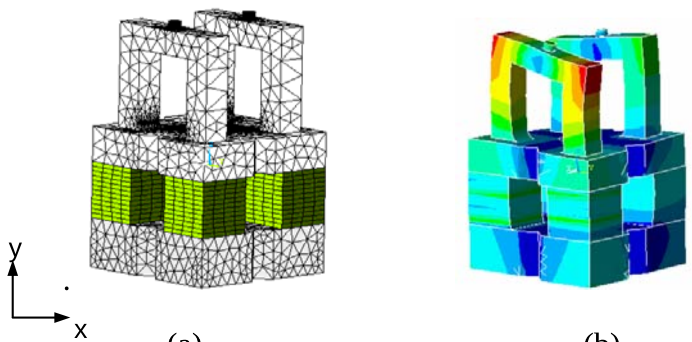


Fig. 1. The position of the beams through every quarter of the oscillations period

FEM modeling of linear piezoelectric motor

FEM modeling was carried out by FEM software (ANSYS 5.7), which was used to create solid FE model to make modal-frequency and harmonic response analysis.



(a) (b)

Fig. 2. FEM analysis of compound piezoelectric linear motor

(a) FE model, (b) Displacement of the motor (60.06 KHz)

A full harmonic response analysis was performed by Incomplete Cholesky Conjugate Gradient solver with tolerance 10^{-6}. Piezoelements of the motors were excited with AC signal applied on the electrodes. Amplitude of the voltage was 100V and the difference

of the phases of applied voltage was 90° for each piezoelement. Displacement of the compound piezoelectric linear motor after quarter of period is shown in Figs. 2(a) and 2(b).

The main task of harmonic response analysis is to find out trajectory of motion of contact points, which are located on the top of the piezomotor shaft. The results are shown in Fig. 4. Trajectory of contact points movement is elliptical shape in yz plane. Angles of rotation are 34.65 ° for first contact node and -36.51° for second contact node of the compound actuator. Displacements of x direction are ignored because they are much smaller than displacements in other directions and do not have big influence to the trajectory of contact point movement.

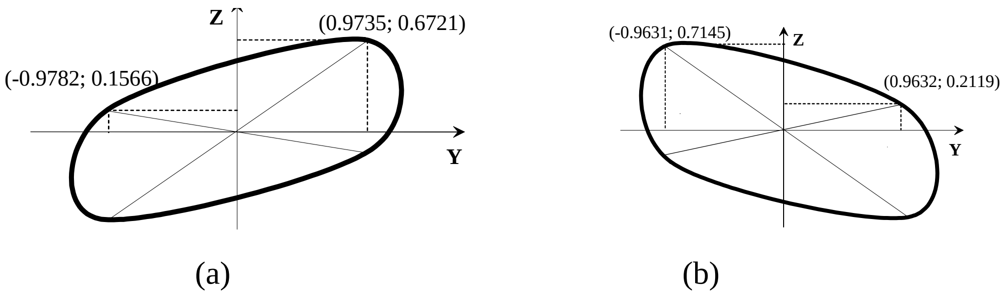


Fig. 4. Motion trajectory of contact points. (a) first point(10^{-8}m), (b) second point

Experimental Results of the piezoelectric linear motor

The dependence of the parameters such as resonant frequency, electrical capacity and driving force of the motor on pressing force applied to the contact point of the actuator was analyzed. Driving forces of the left and right directions of the mobile element was measured using spring dynamometer. The generator was adjusted to the resonant frequency and driving force (F_1) of the mobile element was measured when it moved to the left and to the right. Electrical power P was measured as well. Electrical power was determined as the power that also includes expenses for the circuit generator, that is as power consumption from a source of constant current and the power that was applied to piezoelements actuator.

The results of experimental piezoelectric motor researches are given in the Fig. 5

The driving force F_1 (left and right) of the piezoelectric motor is symmetrical and the optimum of contact force F_2 is between 100 and 110N. The changes of resonant frequency depending on contact force are insignificant and do not exceed 1kHz. The change of the electrical power was from 13 till 20W, when driving force of the motor changes over a wide range from 5 to 29N. It is not shown on the absolutely optimum coordination of the generator output with the motor input.

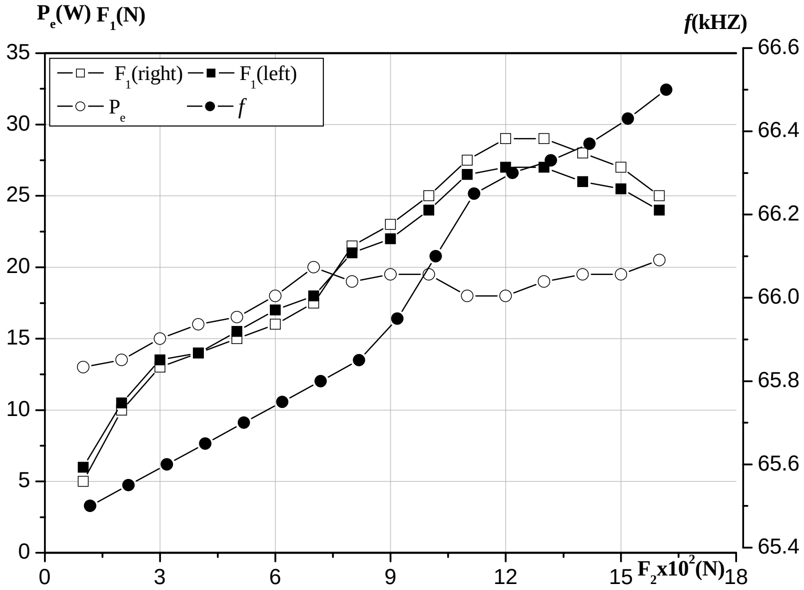


Fig. 5 The characteristics of piezoelectric linear motor
F_1-driving force, F_2 –contact force, *f* –resonance frequency, *P* –electrical power

Conclusions

A principle of the new type piezoelectric motor based on concept of "shaking beam" actuator has been developed. Based on it the compound piezoelectric linear motor has been made to increase the thrust force. The "shaking beam" type actuator and piezoelectric motor using it have confirmed an opportunity of the elliptic trajectory generation with the help of one stable mode of the oscillations.

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